Molecular Minerals on Titan

The Acetylene Series

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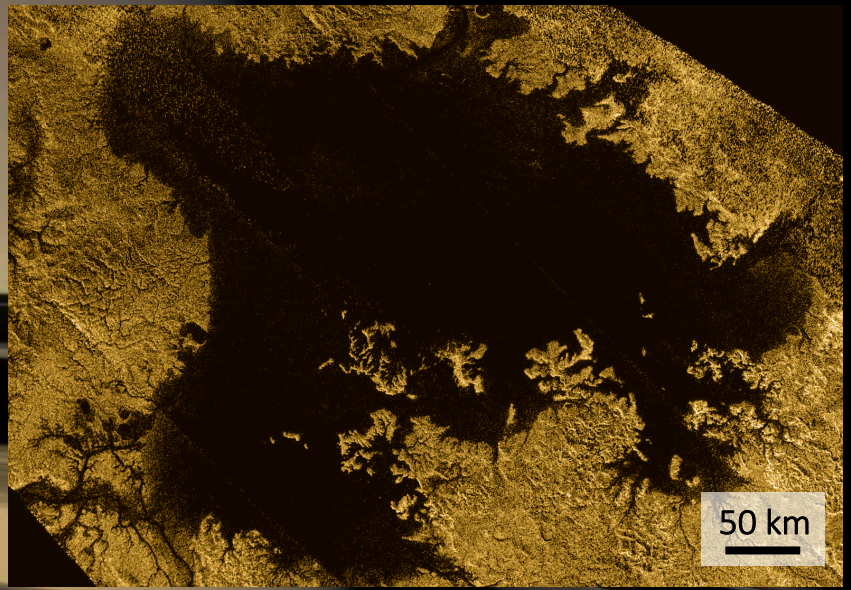
Jet Propulsion Laboratory
California Institute of Technology

Background Image: NASA/JPL-Caltech/SSI

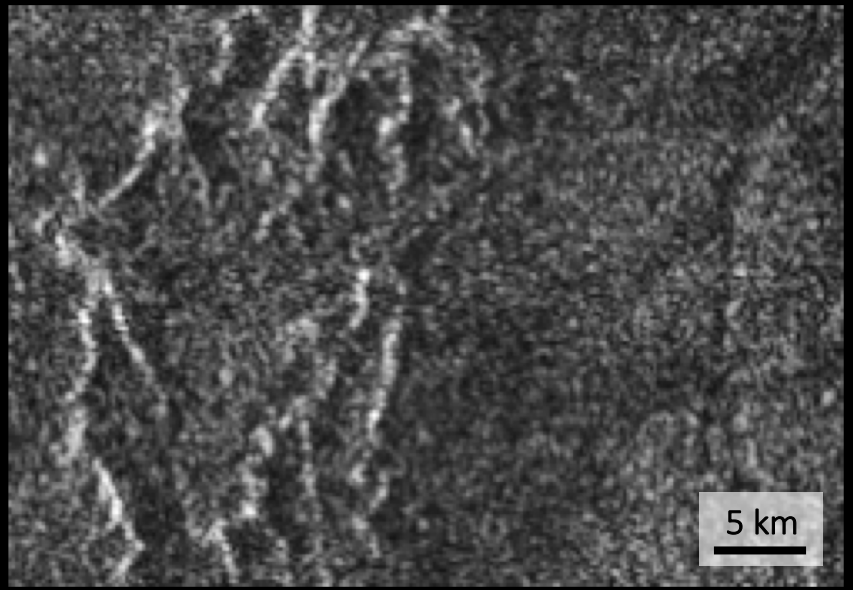
TITAN

An organic chemist's paradise

Lakes and Seas of Methane, Ethane



Remnants of Ridges (Karst)



Images: NASA/JPL-Caltech/ASI/Cornell

Titan Surface Processes

Study the pieces to understand the whole

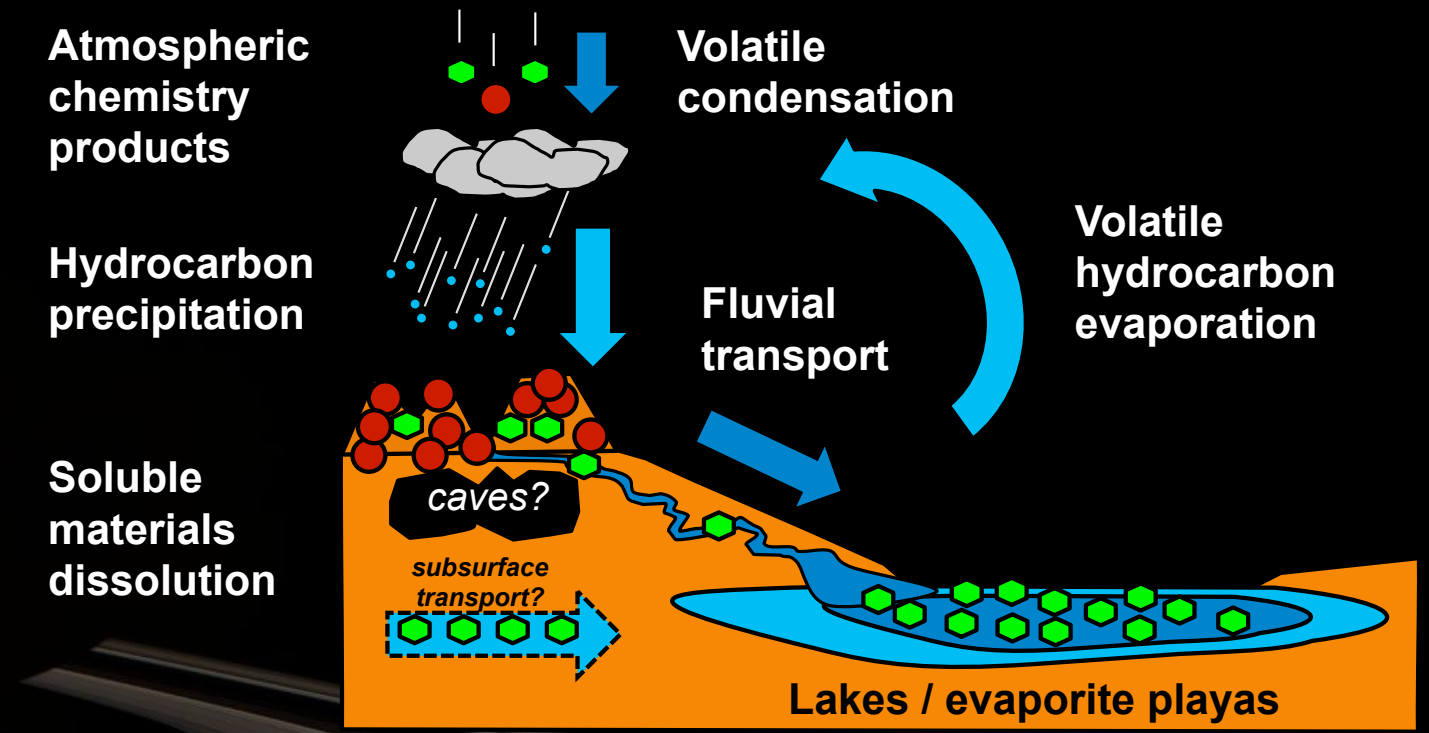


Figure by M. Malaska

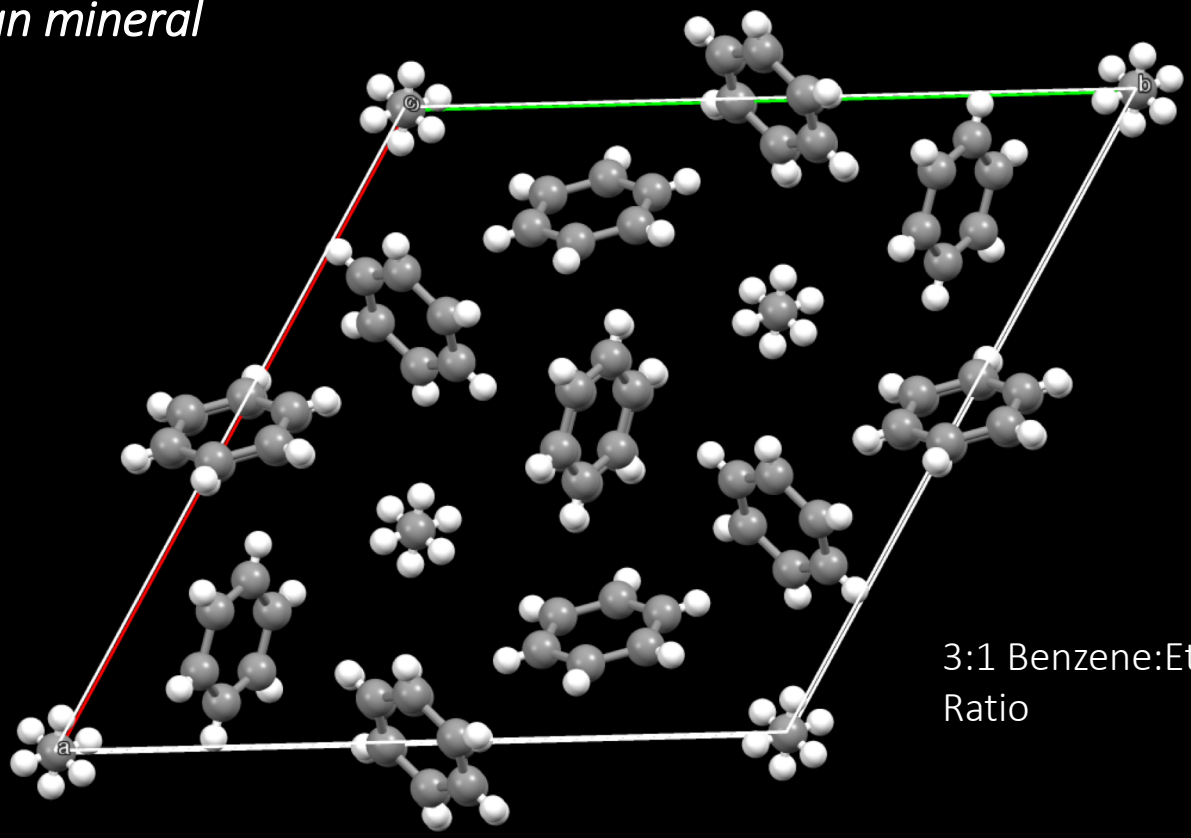
Titan Laboratory Experiments

Tackling Titan's surface chemistry, one experiment at a time

Photo/images: M. Cable

Benzene-Ethane Co-Crystal

The first discovered Titan mineral



3:1 Benzene:Ethane Ratio

Maynard-Casely et al., **2016**, *Int. Union of Crystallography J.*, 3,1-8.

Benzene-Ethane Co-Crystal

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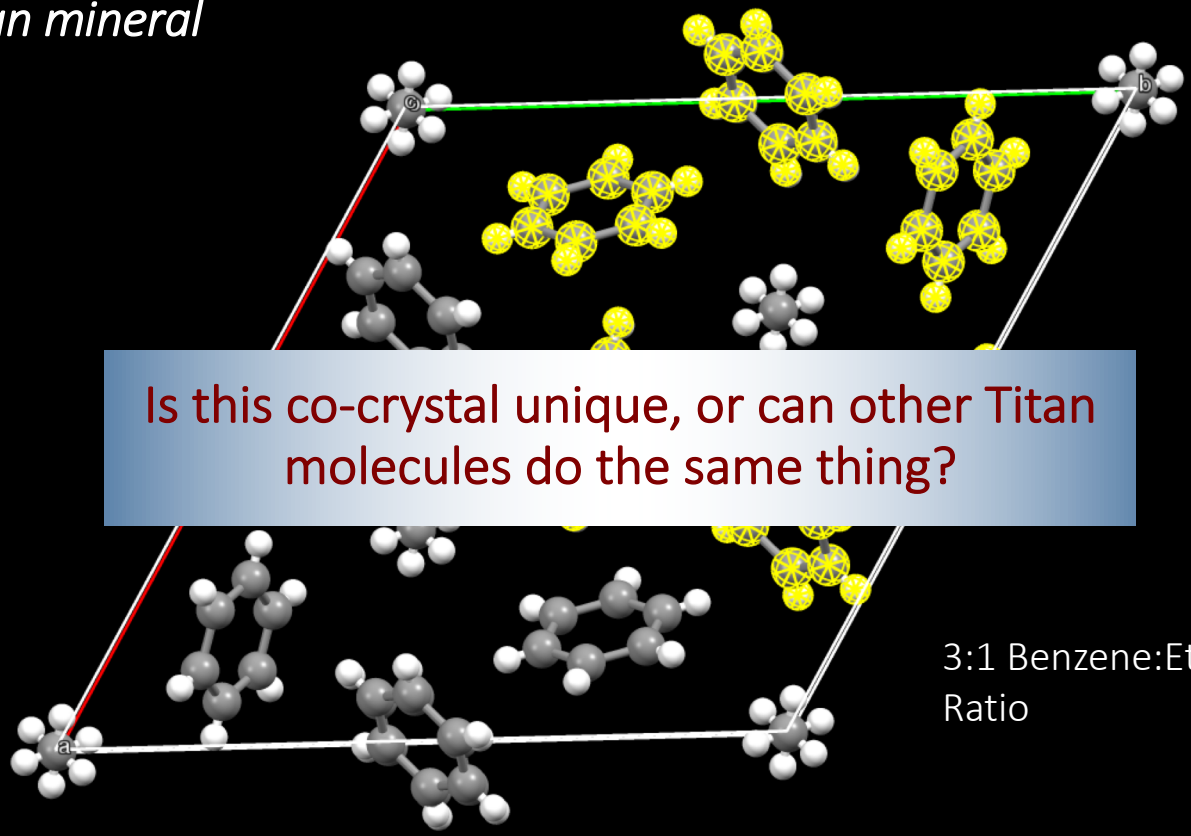


Is this co-crystal unique, or can other Titan molecules do the same thing?

3:1 Benzene:Ethane Ratio

Maynard-Casely et al., **2016**, *Int. Union of Crystallography J.*, 3,1-8.

Acetylene Loves to Form Co-Crystals

Can acetylene form co-crystals under Titan-like conditions?

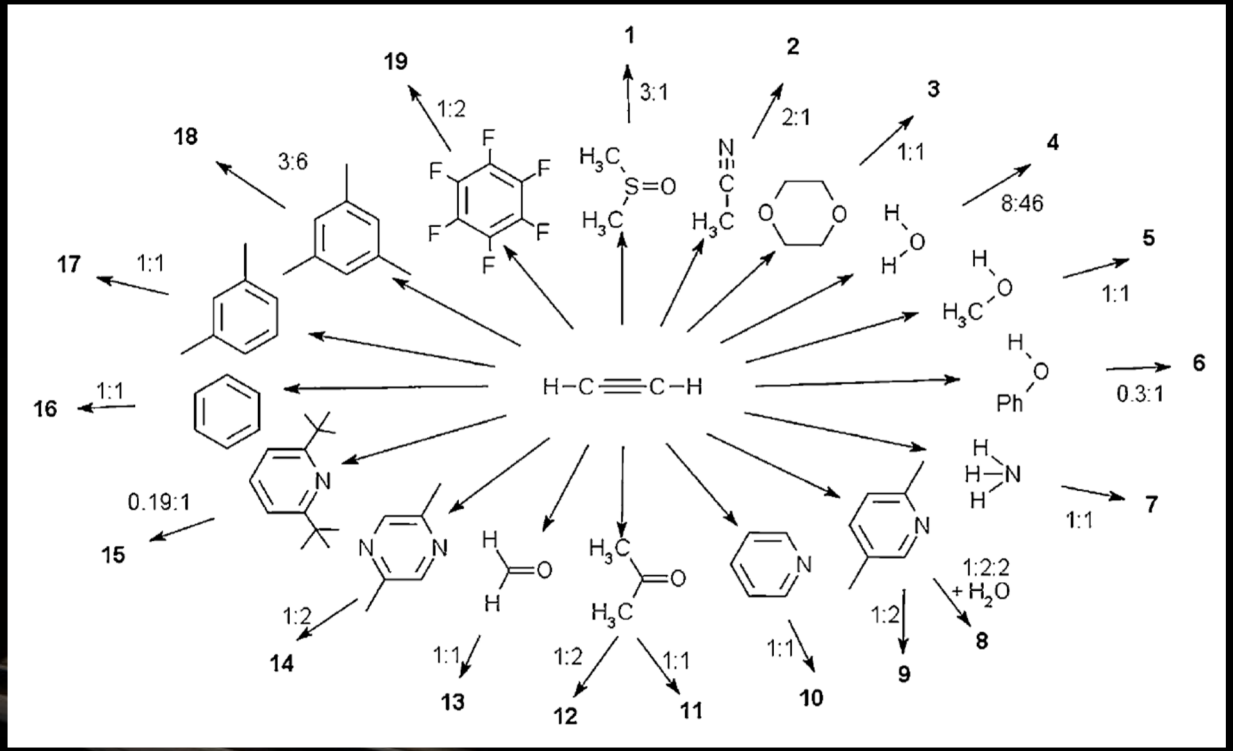
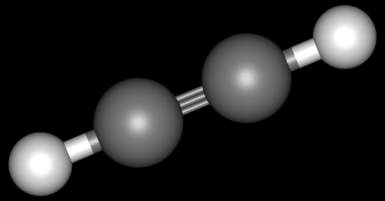
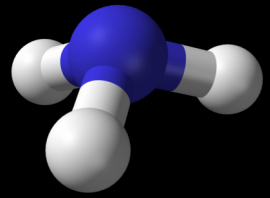


Figure: Kirchner, M. T. et al., **2010**, *Chem. – A Eur. J.*, 16 (7), 2131-2146.

Acetylene and Ammonia

Another co-crystal?





Evidence of Cryovolcanism

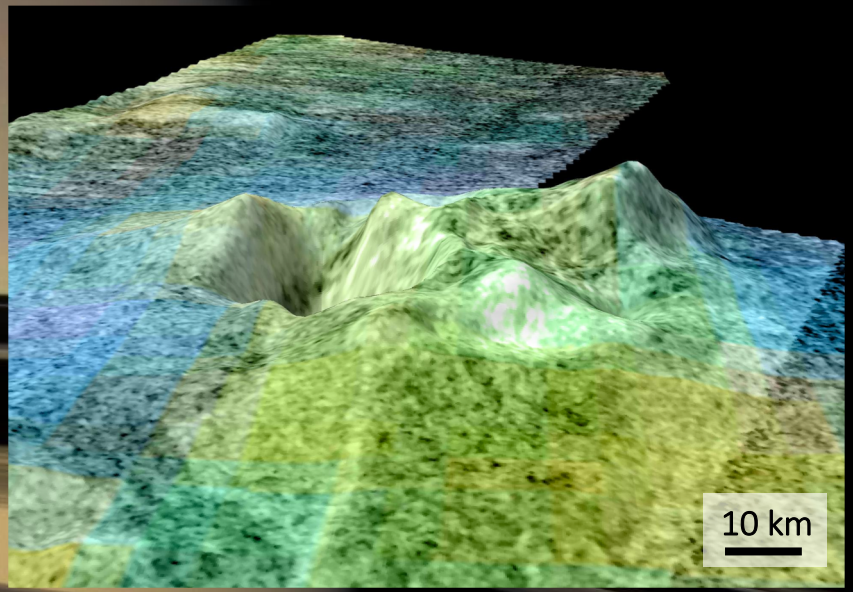


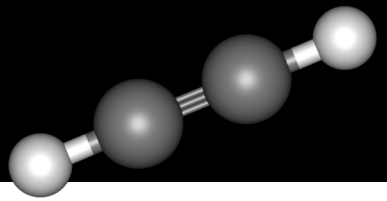
Image: NASA/JPL Caltech/USGS/University of Arizona

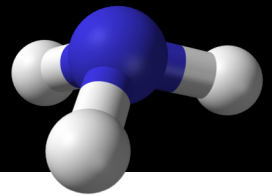
- Acetylene is one of the most abundant solids produced via photochemistry on Titan
  - Detected in the atmosphere by INMS[1] and on the surface by Huygens GC-MS[2]
- Ammonia may also exist on Titan's surface today
  - The origin of Titan's nitrogen-rich atmosphere is most likely ammonia ice[1,3]
  - Mixing could occur via cryovolcanism or other surface processes[4,5]

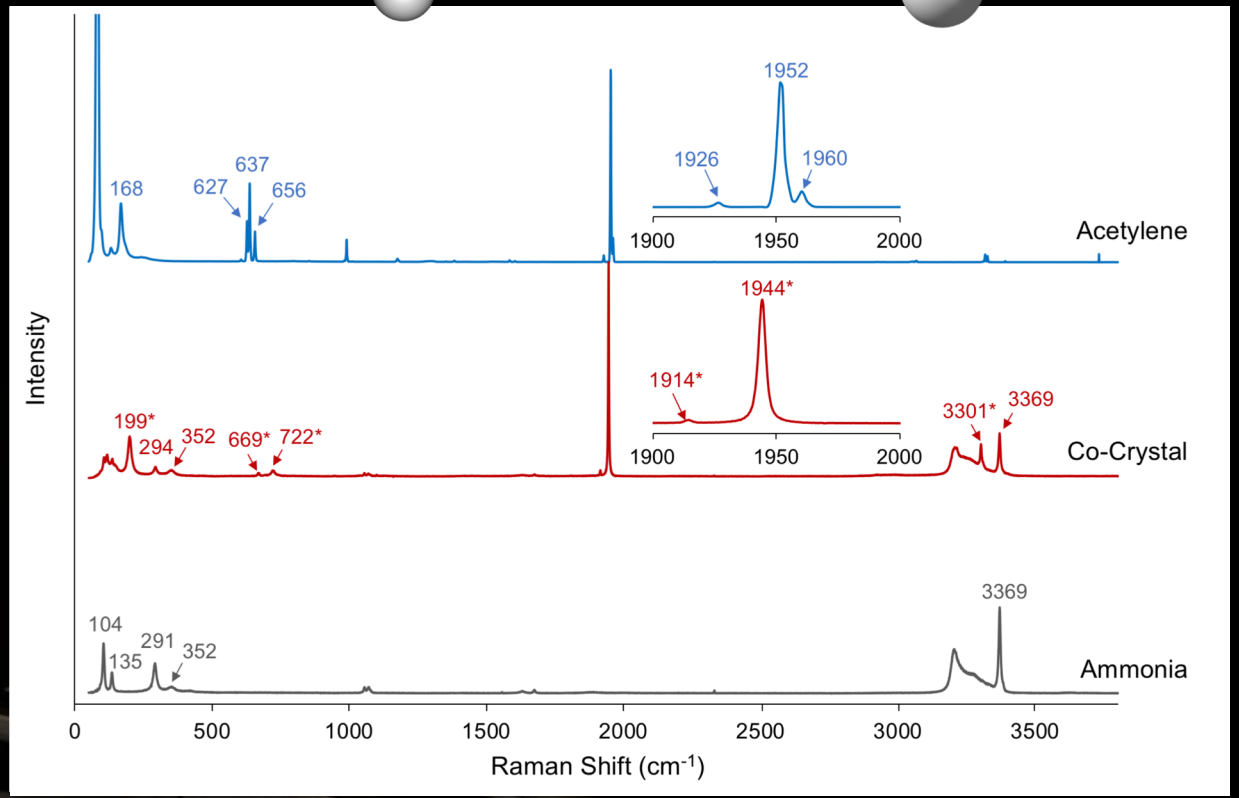
1) Waite et al., **2005**, *Science*, 308, 982-986.
2) Niemann et al., **2010**, *JGR*, 115, E12006.
3) Mandt et al., **2014**, *Astrophys. J. Lett.*, 788, L24, 1-5.
4) Lopes et al., **2013**, *JGR*, 118, 416-435.
5) Nelson et al., **2009**, *Icarus*, 199, 429-441.

Acetylene and Ammonia

New features in Raman



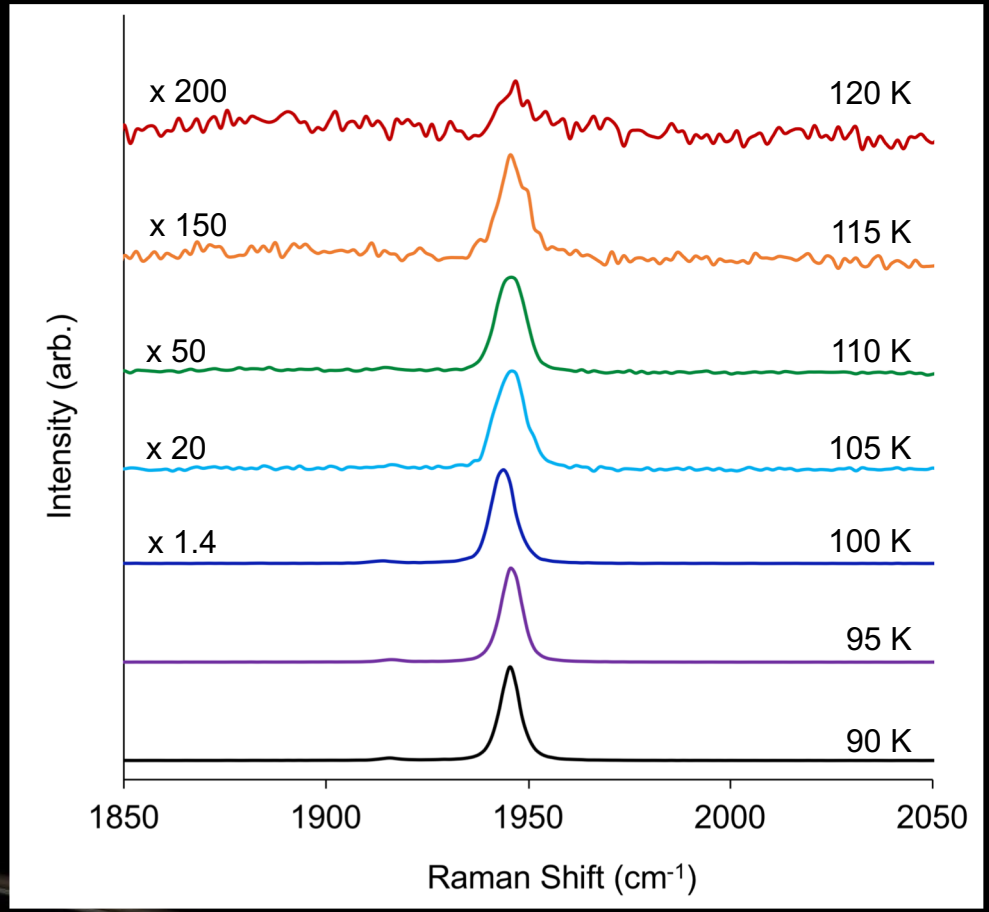




Cable, M. L. et al., **2018**, *Earth Space Chem.*, 2 (4), 366-375.

Acetylene and Ammonia

Co-crystal is stable up to 115 K



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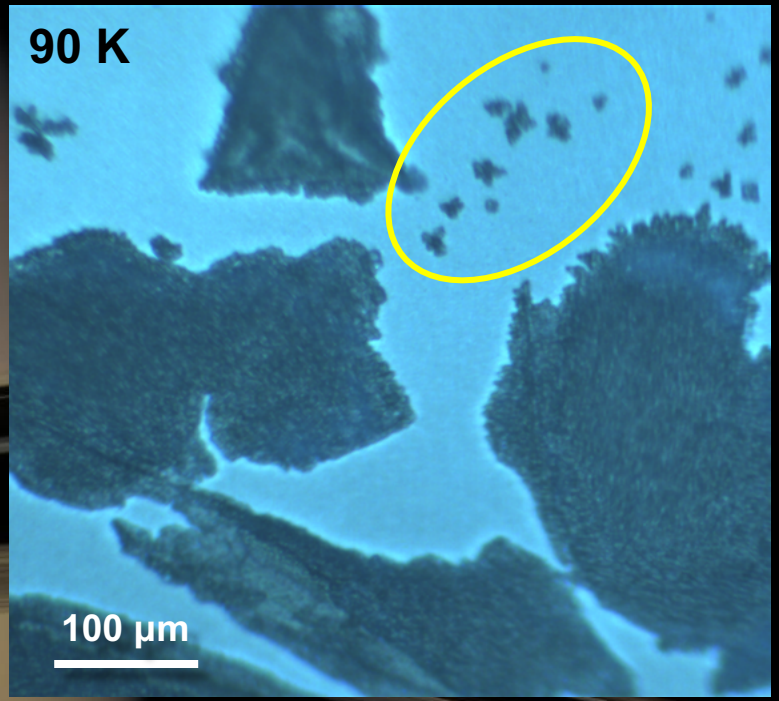
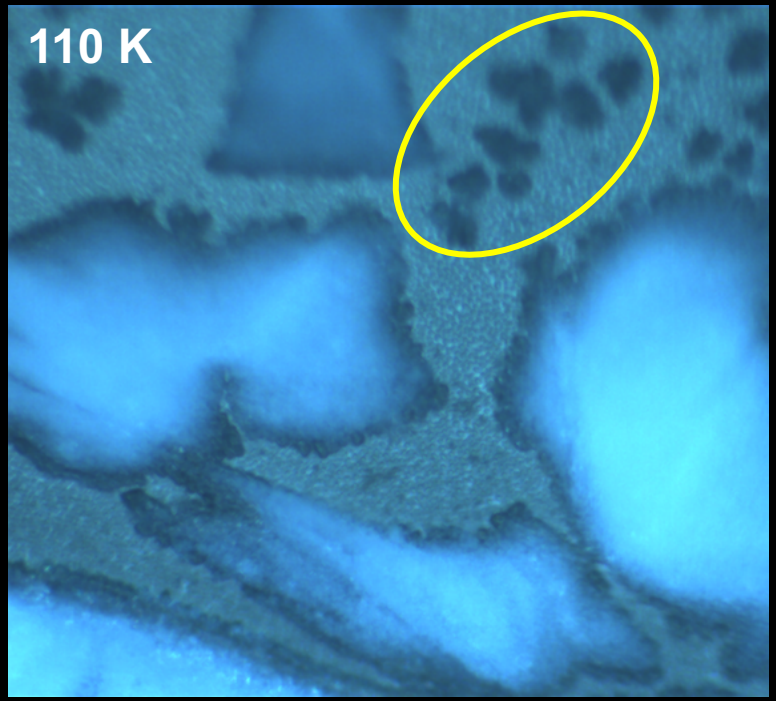
Acetylene and Ammonia

Evidence for expansion of the co-crystal upon heating





Images: T. Vu, R. Hodyss and M. Cable

Cable, M. L. et al., **2018**, *LPSC*, abstract no.2717.

Benzene and Ethane

High thermal expansion

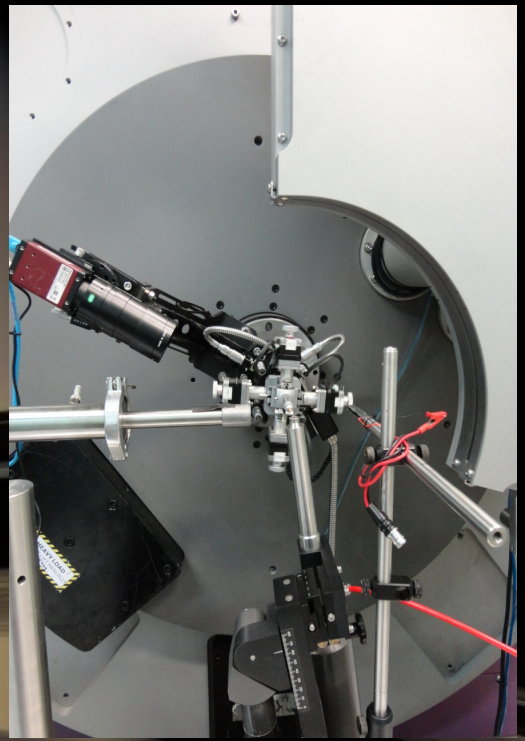
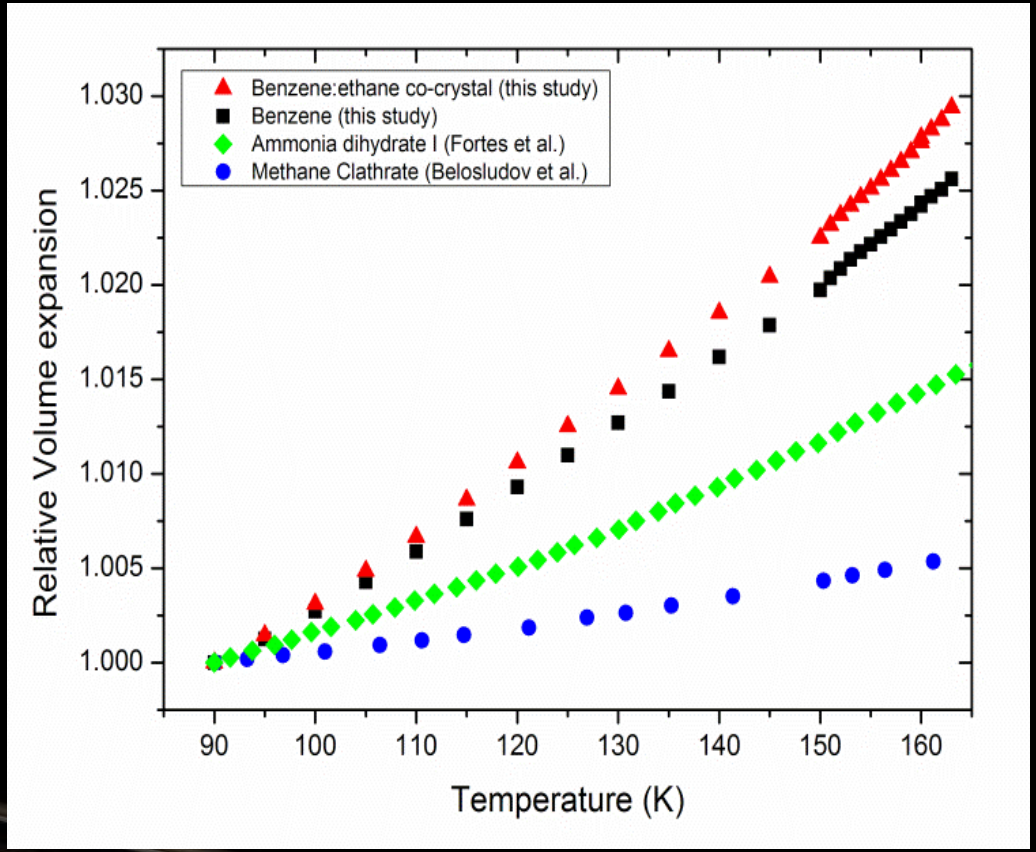


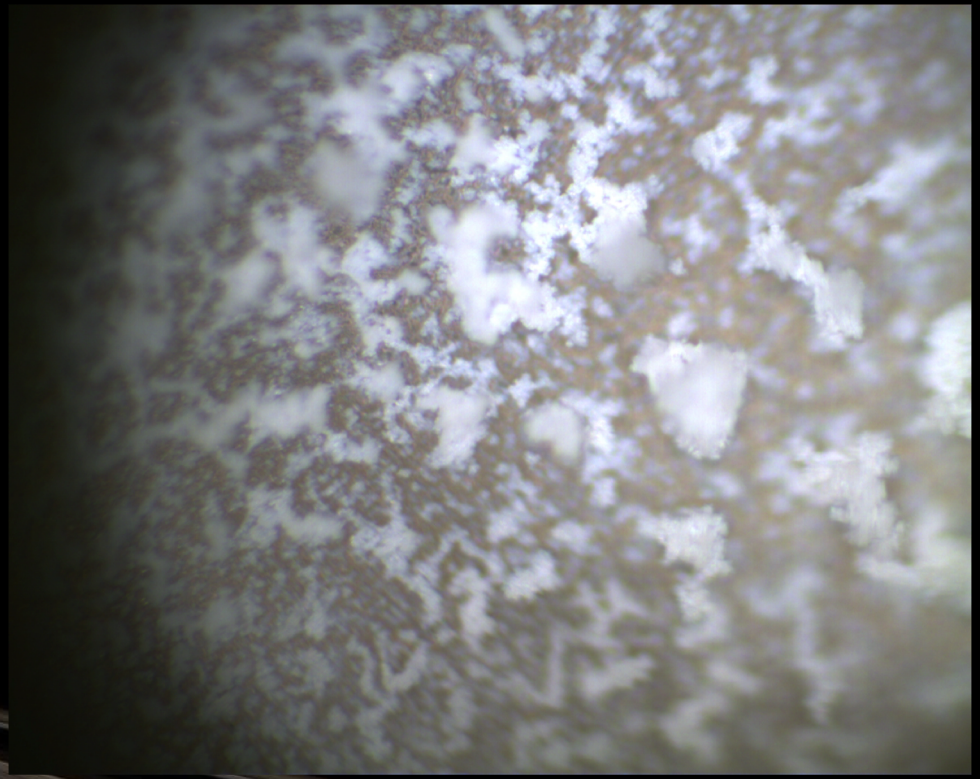
Image: H. Maynard-Casely



Maynard-Casely et al., **2016**, *IUCrJ*, 3 (3), 192–199.

Acetylene and Ammonia

Stable when exposed to hydrocarbon fluvial and pluvial events

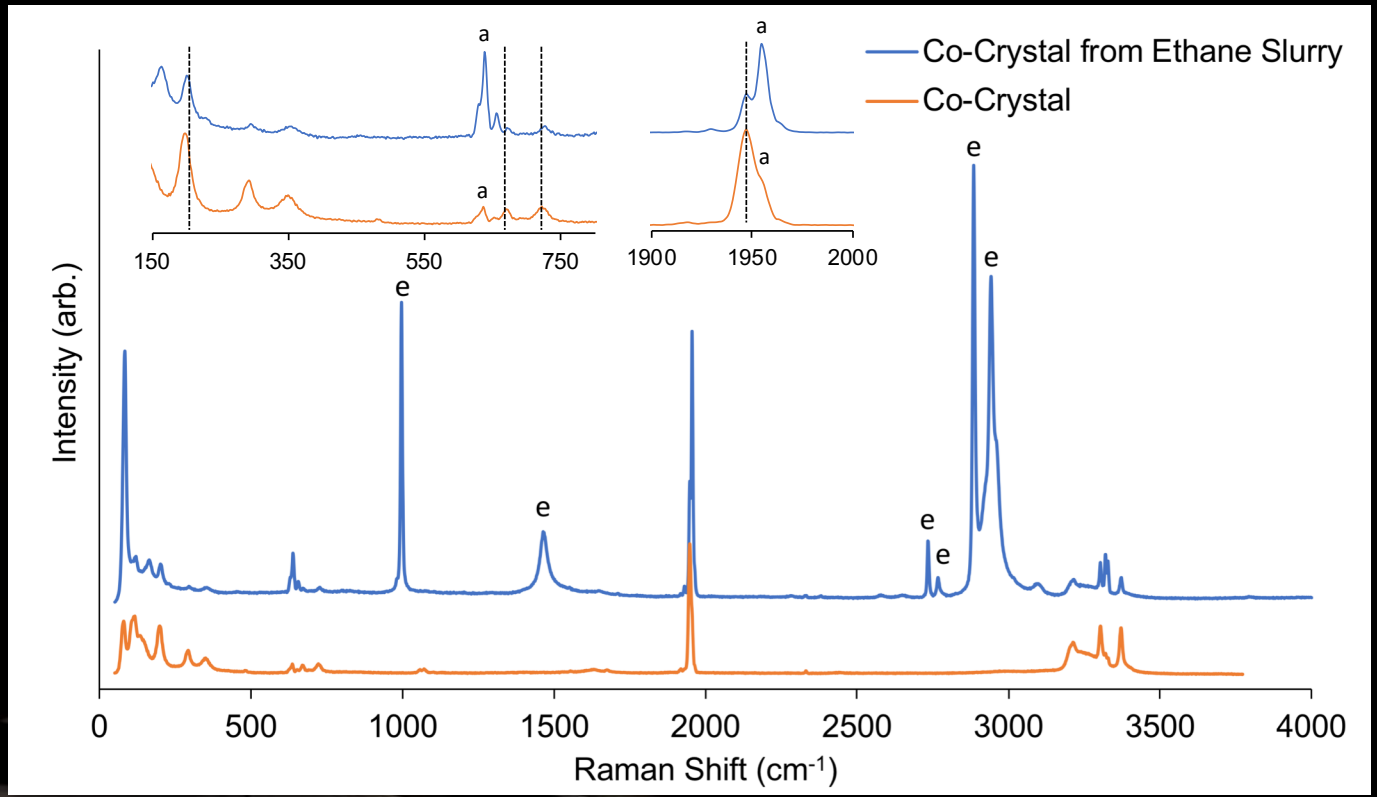


Video: M. Cable, R. Hodyss, T. Vu

Cable, M. L. et al., **2018**, *Earth Space Chem.,* 2 (4), 366-375.

Acetylene and Ammonia

Co-crystal still forms from fluvial deposition via acetylene-saturated ethane slurry



Acetylene Loves to Form Co-Crystals

Can acetylene form other co-crystals under Titan-like conditions?

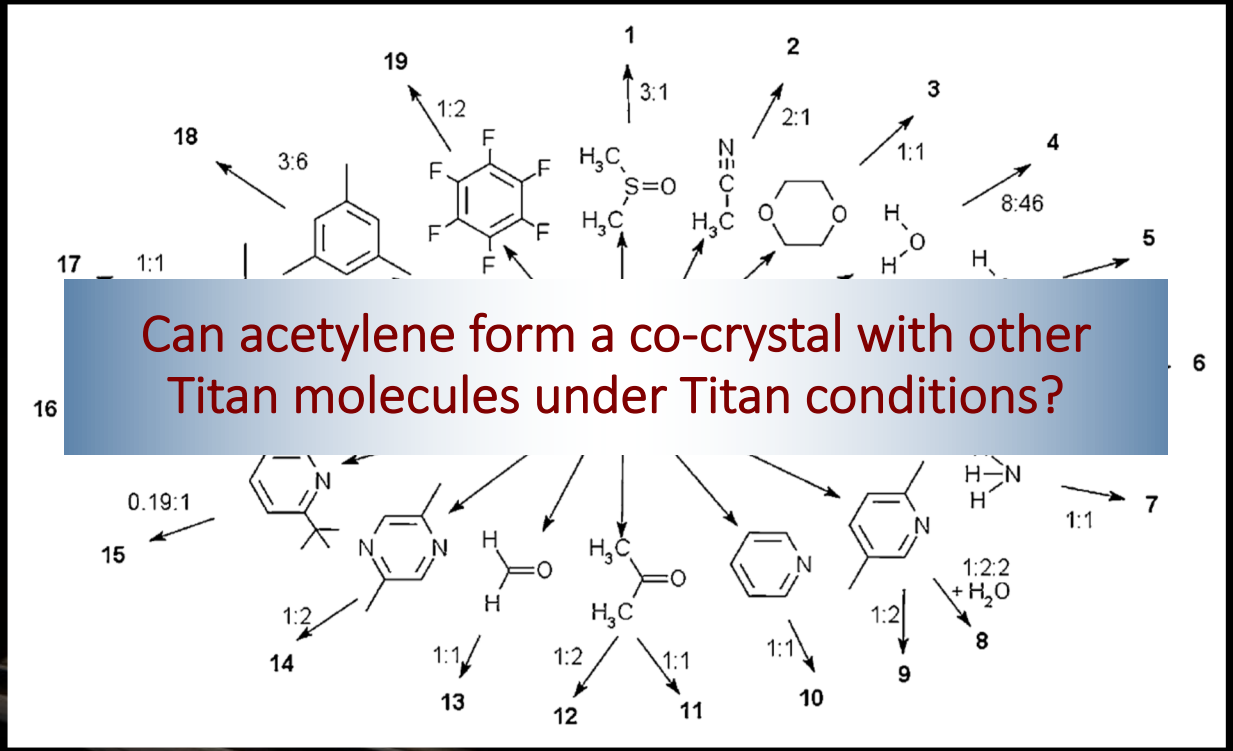
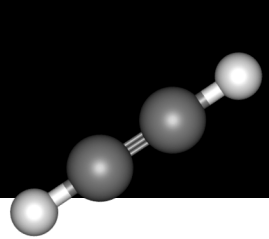
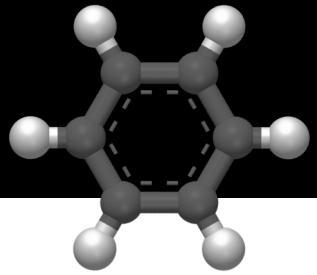


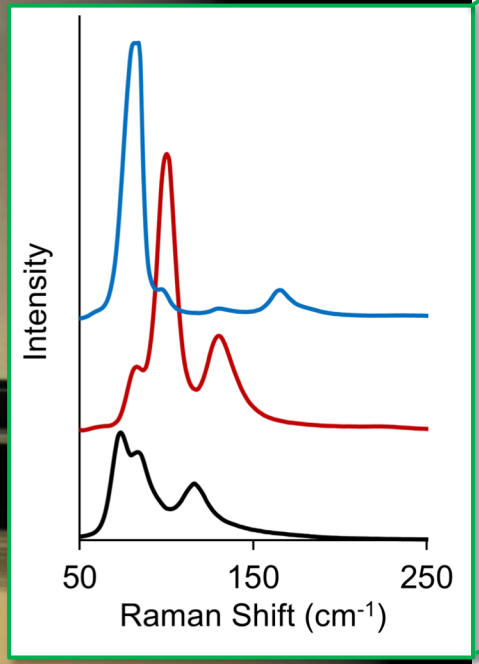
Figure: Kirchner, M. T. et al., **2010**, *Chem. – A Eur. J., 16 (7), 2131-2146.*

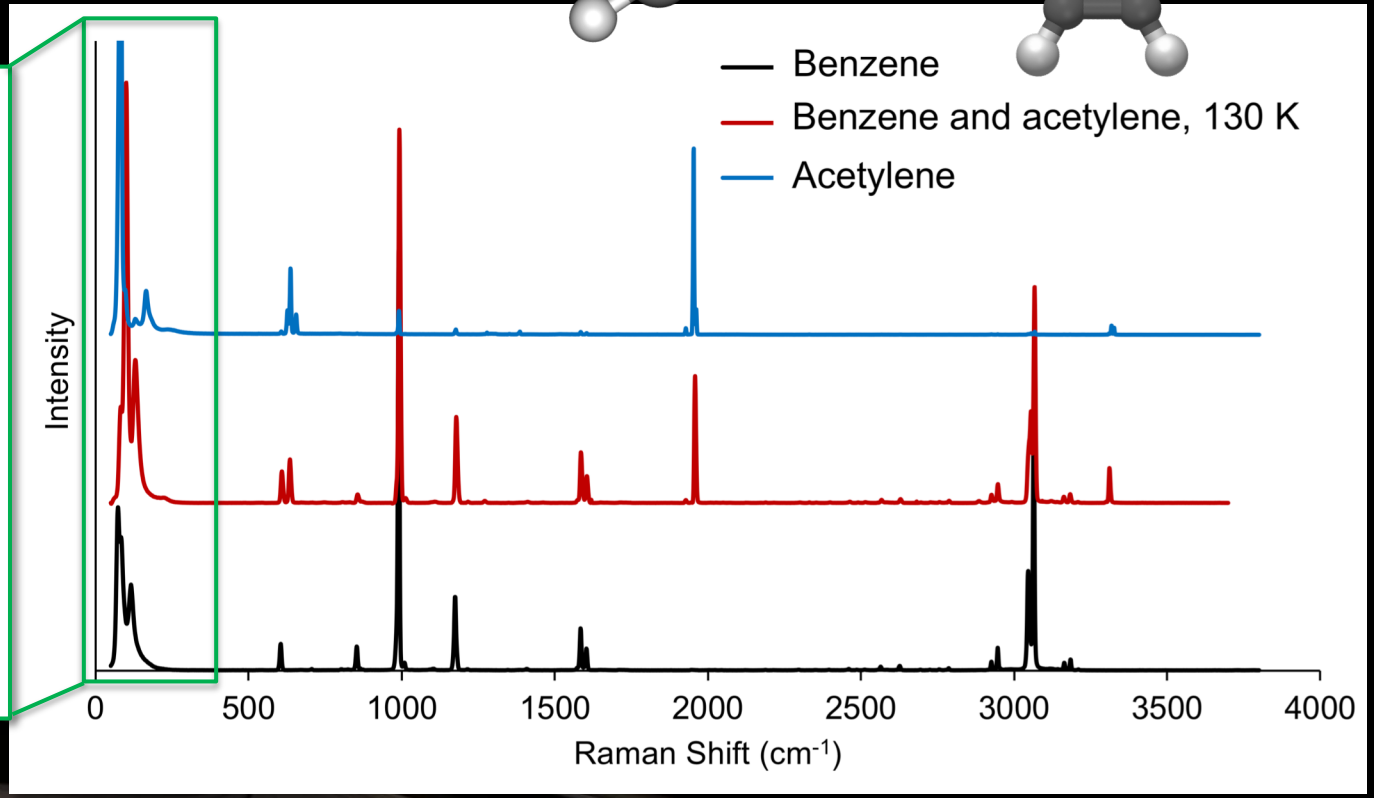
Acetylene and Benzene

Preliminary evidence









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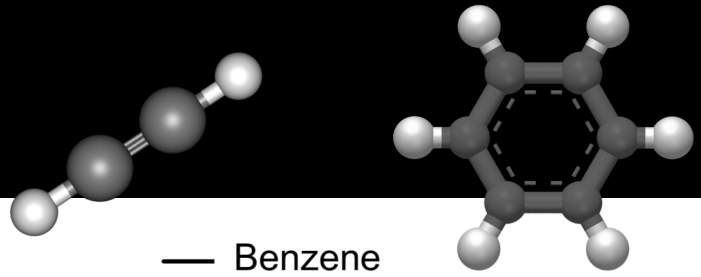

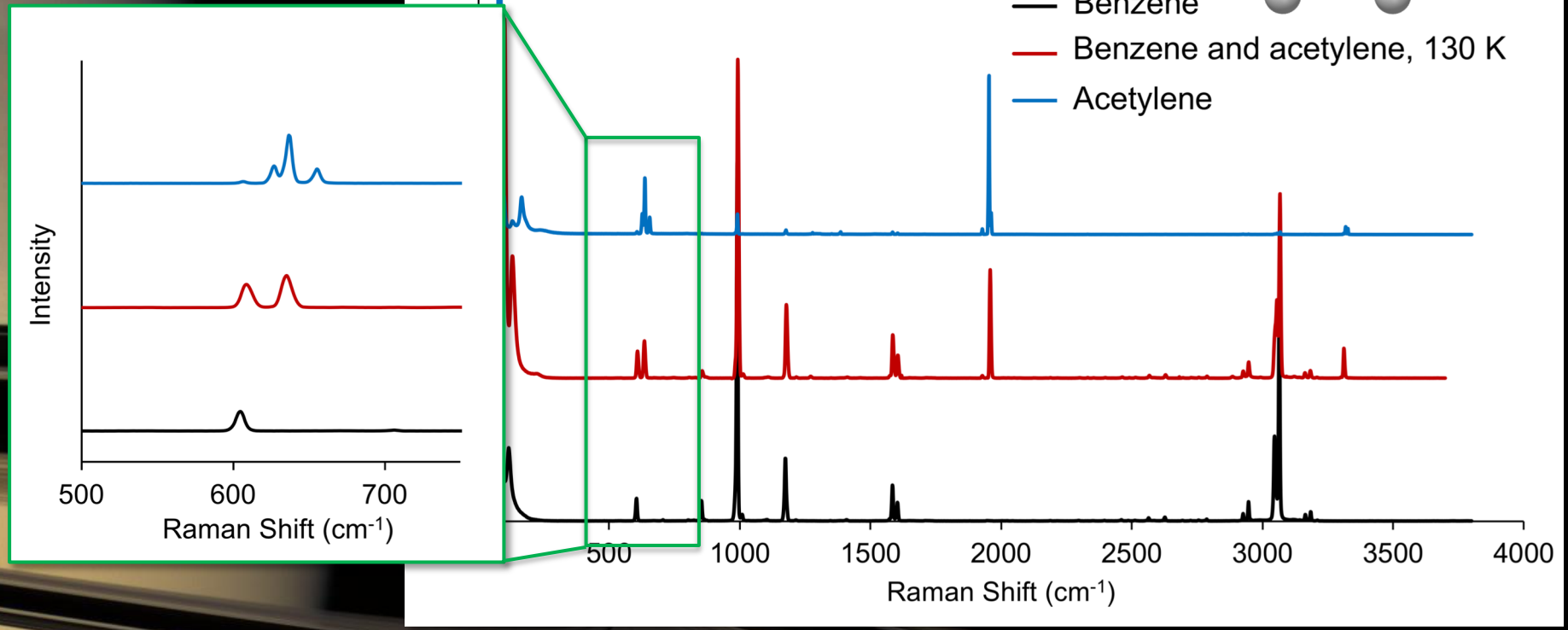

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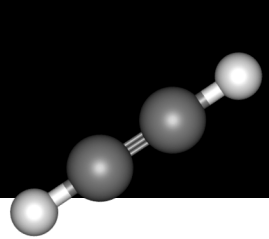

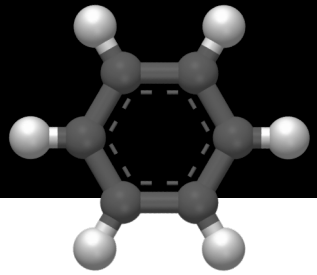

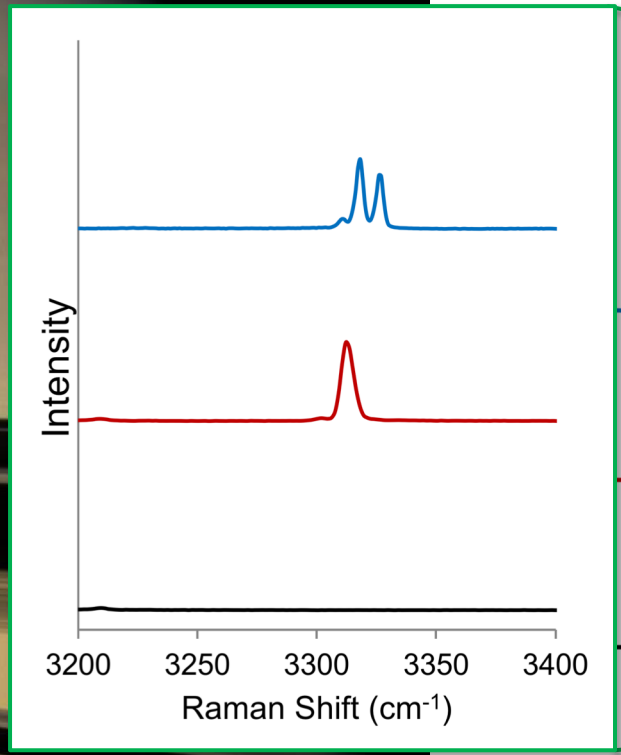

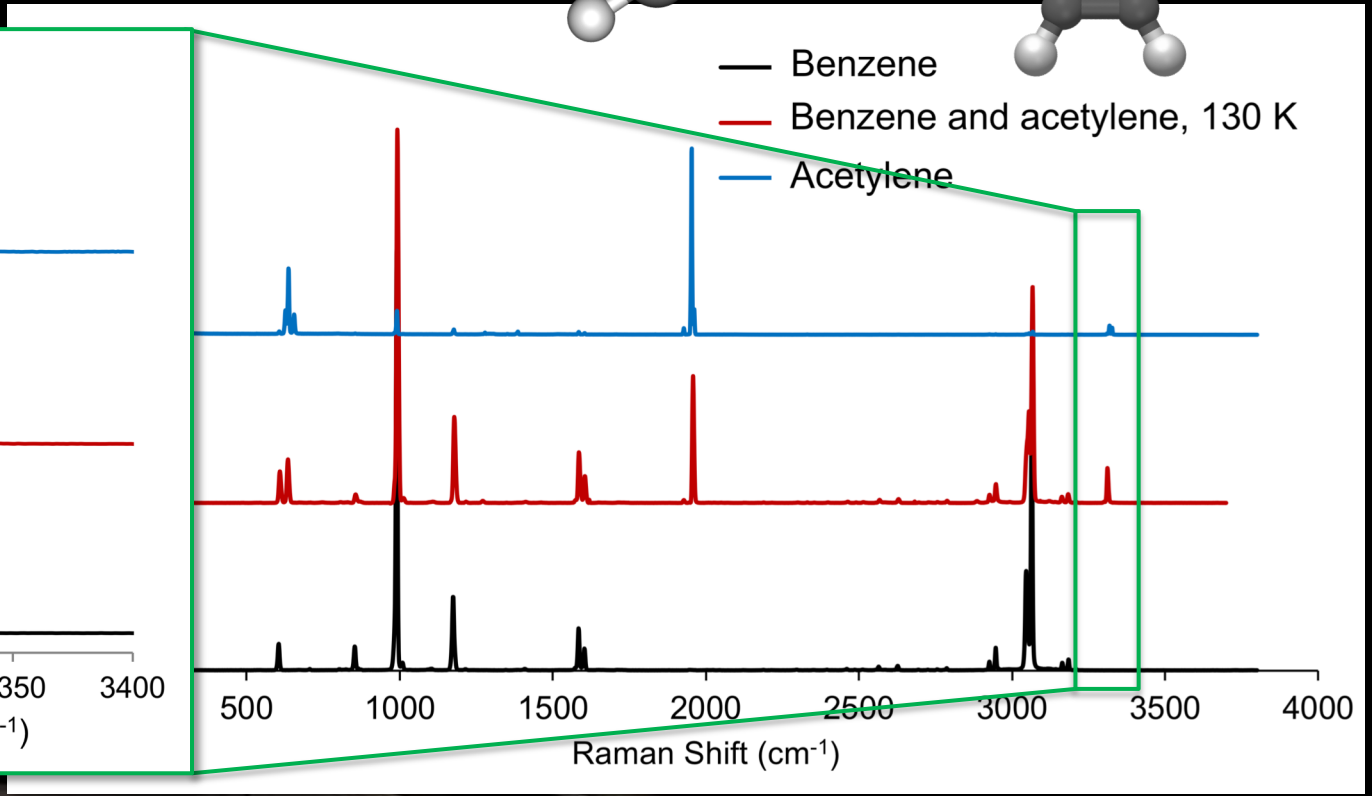

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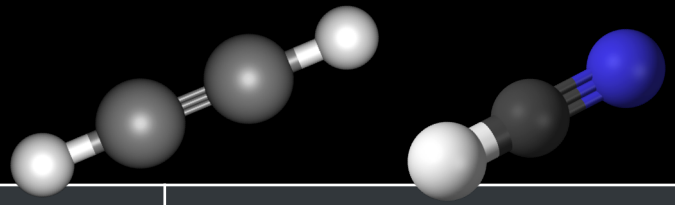
Acetylene and HCN

The beginnings of an acetylene series . . .



Species	Formula	Precipitation Rate (x 10^5 molecules·m^{-2}·s^{-1})
Hydrogen cyanide	HCN	1300
Butane	C_4H_{10}	540
Acetylene	C_2H_2	510
Acetonitrile	CH_3CN	44
Carbon dioxide	CO_2	13
Benzene	C_6H_6	10

Table: Cordier, D. et al., **2013**, *Icarus*, 226 (2), 1431-1437.

Acetylene and HCN

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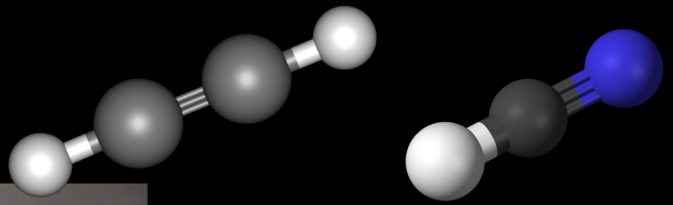

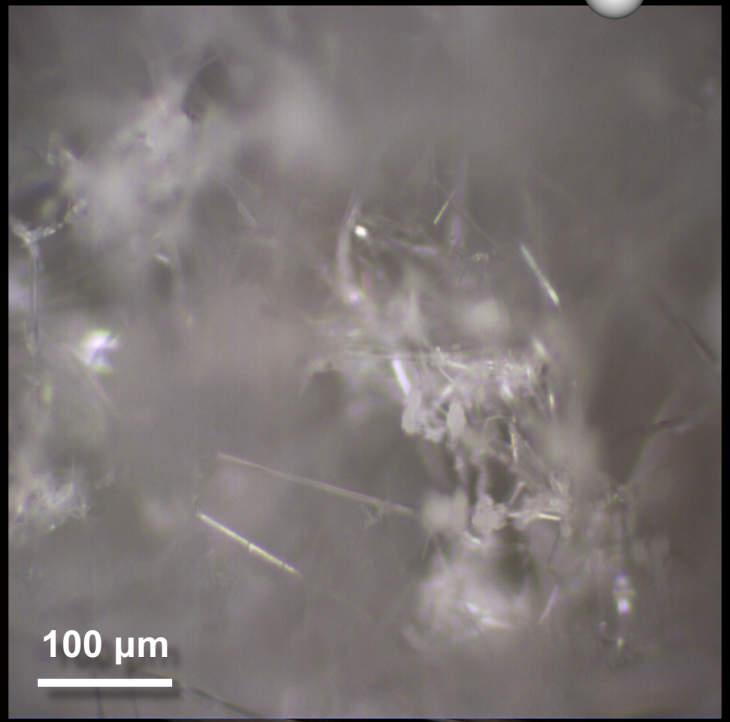

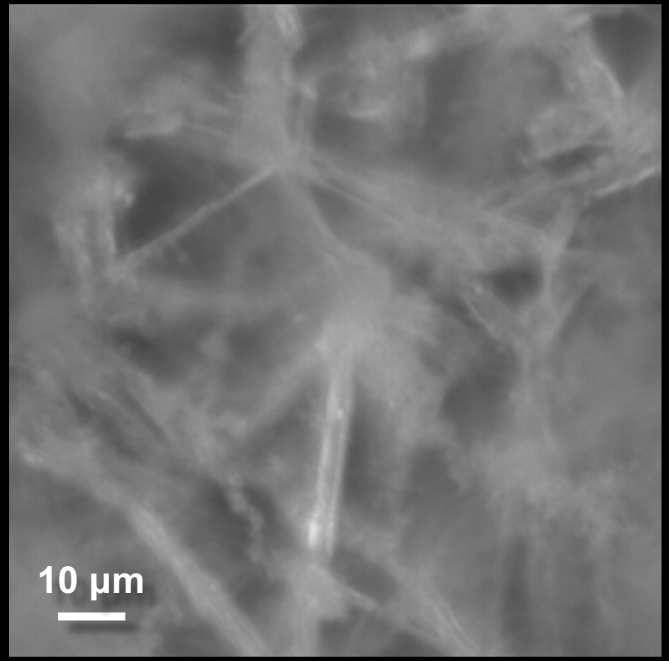

Images: T. Vu, R. Hodyss and M. Cable

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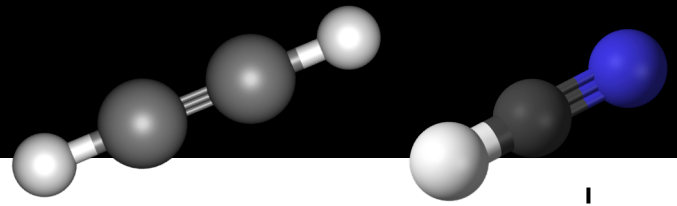

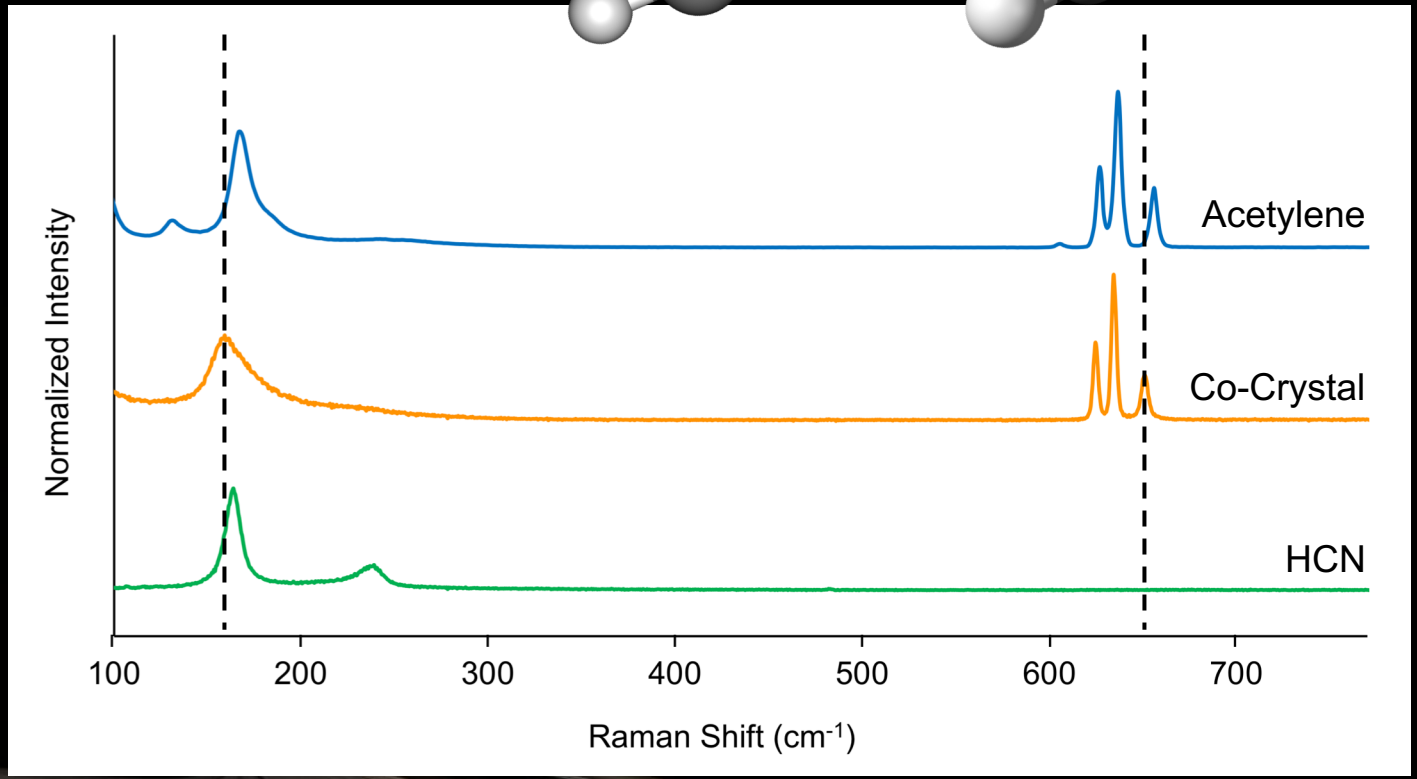

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Titan Laboratory Experiments: Conclusions

Learning what makes Titan tick

- Organic co-crystals may be abundant on Titan, and may assume the role of minerals on Earth.
- A series of acetylene-based molecular minerals may exist on Titan.
- Co-crystals may be responsible for surface material characteristics such as particle size, dissolution rate, structural hardness, and resistance to erosion.
- Differences in physical or mechanical properties may also lead to chemical gradients, which life could potentially exploit.

What does this mean for the Dragonfly Concept?

Detection of co-crystals or their effects on the surface

- **DraMS:** Ratios of small organics consistent with co-crystals (ethane/benzene, acetylene/ammonia)
- **DraGNS:** Elemental abundances consistent with co-crystals
- **DraGMet:** Differences in relative humidity of methane to ethane due to ethane being entrained within co-crystalline structures
- **DragonCam:** Enhanced erosion or slopes consistent with smaller-than-anticipated grain sizes (due to recrystallization); evidence of terrain that has undergone volumetric expansion (possibly due to thermal expansion of co-crystal reservoirs)

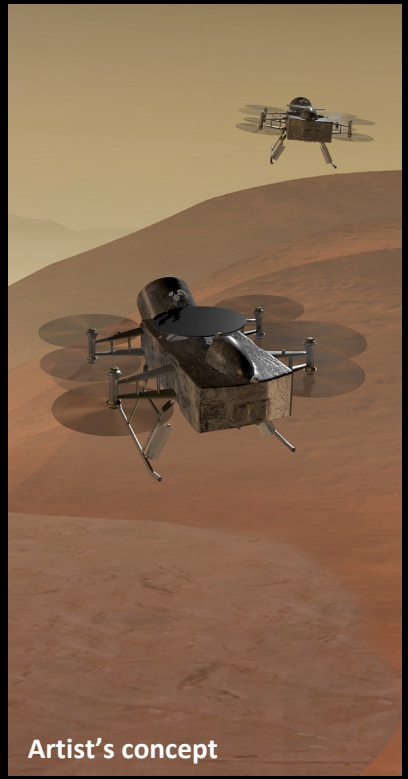

Image: Artist's concept, JHU-APL

Acknowledgements

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- Tuan Vu
- Mike Malaska
- Helen Maynard-Casely
- Mathieu Choukroun
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- NASA Solar System Workings
- Australian Nuclear Science and Technology Organisation

Jet Propulsion Laboratory
California Institute of Technology

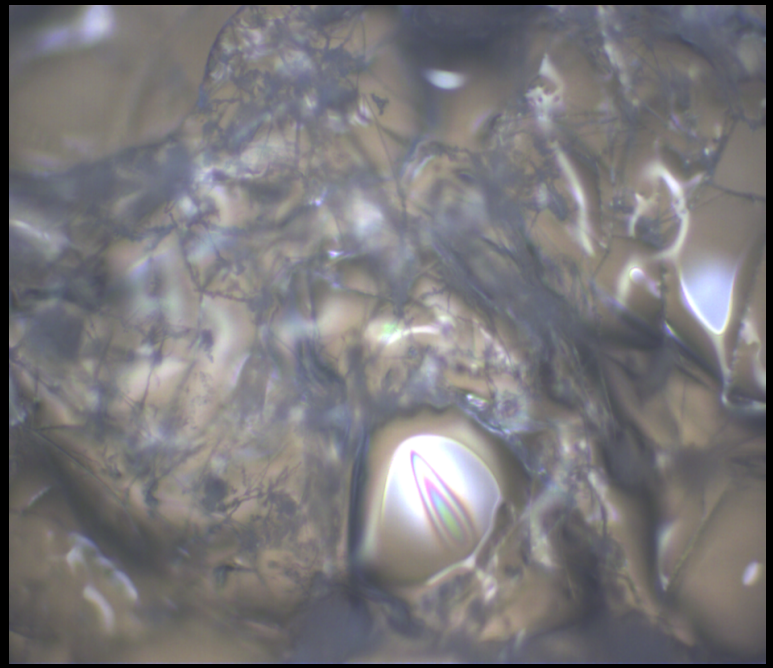

Image: T. Vu, R. Hodyss and M. Cable